

Power Quality Improvement for Non Linear Load by Using DSTATCOM

B. Silvin Daniel, R. Ilango, V. Prabakaran

Abstract—The researchers are more importance to power quality problems. Various power quality problems are voltage sag, voltage swell, harmonics, interruptions etc. This paper proposes to reduction the Total Harmonic Distortion (THD) in power system. The total harmonic distortion is reduced using distribution static compensator (DSTATCOM). An Instantaneous d-q theory has been used for controlling switching converter which calculates the required current injected into the power system. The simulated results show the effectiveness of DSTATCOM in reducing the harmonic distortion.

Index Terms—Reactive power compensation, DSTATCOM, dq theory, Power quality.

I. INTRODUCTION

In the early days of power transmission in the late 19th century problems like voltage deviation during load changes and power transfer limitation were observed due to reactive power unbalances. Most of the AC loads are consuming reactive power due to presence of reactance. Heavy consumption of reactive power causes poor voltage quality. Today these Problems have even higher impact on reliable and secure power supply in the world of Globalization and Privatization of electrical systems and energy transfer. The development in fast and reliable semiconductors devices (GTO and IGBT) allowed new power electronic Configurations to be introduced to the tasks of power Transmission and load flow control. The FACTS devices offer fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. On the other hand the custom power is for low voltage distribution, and improving the poor quality and reliability of supply affecting sensitive loads. Custom power devices are very similar to the FACTS. Most widely known custom power devices are DSTATCOM, UPQC, DVR among them DSTATCOM is very well known and can provide cost effective solution for the compensation of reactive power and unbalance loading in distribution system. The performance of the DSTATCOM depends on the control algorithm i.e. the extraction of the current components [1]. For this purpose there are many control schemes which are reported in the literature and some of these are instantaneous reactive power (IRP) theory, instantaneous

compensation, instantaneous symmetrical components, synchronous reference frame (SRF) theory [2]. Among these control schemes instantaneous reactive power theory and synchronous rotating reference frame are most widely used. This paper focuses on the reducing the total harmonic distortion. The dynamic performance is analyzed and verified through simulation. It is a custom power device which is gaining a fast publicity during these days due to its exceptional features like it provides fast response, suitable for dynamic load response or voltage regulation and automation needs, Both leading and lagging VARS can be provided, to correct voltage surges or sags caused by reactive power demands DSTATCOM can be applied on wide range of distribution and transmission voltage, overload capability of this provides reserve energy for transients [3,4].

The causes of power quality problems are generally complex and difficult to detect. Technically speaking, the ideal AC line supply by the utility system should be a pure sine wave of fundamental frequency (50/60Hz). Different power quality problems, their characterization methods and possible causes are discussed above and which are responsible for the lack of quality power which affects the customer in many ways. We can therefore conclude that the lack of quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained [5]. This project demonstrates that the power electronic based power conditioning using custom power devices like DSTATCOM can be effectively utilized to improve the quality of power supplied to the customers.

II. DISTRIBUTED STATIC COMPENSATOR (DSTATCOM)

The Distribution Static Compensator (DSTATCOM) is a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage the concept of STATCOM was proposed by Gyugyi in 1976. Power Converter employed in the STATCOM mainly of two types i.e. is Voltage Source Converter and Current Source Converter. In Current source Converter direct current always has one polarity and the power reversal takes place through reversal of dc voltage polarity while In Voltage Source Converter dc voltage always has one polarity, and the power reversal takes place through reversal of dc current polarity. The power semiconductor devices used in current source converter requires bidirectional voltage blocking capability and for achieving this Characteristic an additional diode must be connected in series with a

B. Silvin Daniel, PG Student, Electrical Engineering Department, M.A.M School of Engineering, Trichy, India.

R. Ilango, Head and Professor, Electrical Engineering Department, M.A.M School of Engineering, Trichy, India.

V. Prabakaran, Assistant Professor, Electrical Engineering Department, M.A.M School of Engineering, Trichy, India.

semiconductor switch which increased the system cost and it becomes costlier as compared to voltage source converter moreover Voltage source converter can operate on higher efficiency in high power applications. Because of the above reasons Voltage source converter is preferred over Current source converter and now these days it act as a basic electronic block of a STATCOM that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle. In STATCOM different technologies used dependent upon the power ratings of STATCOM. For higher power STATCOMs GTO based technologies are used while for lower power STATCOMs IGBT based technologies used. The major components of a DSTATCOM are shown in Fig.1.

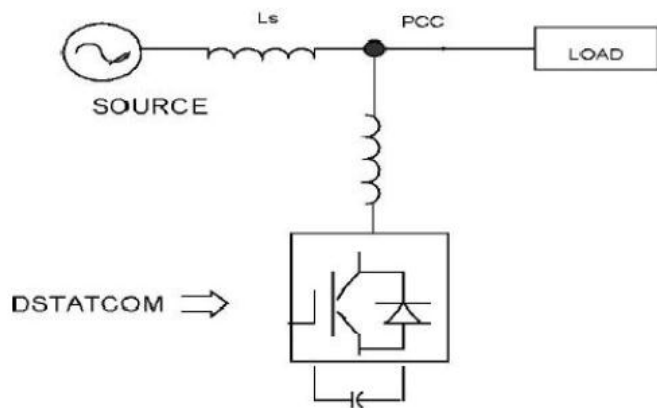


Fig. 1. Block diagram of DSTATCOM circuit.

A. DSTATCOM Components

1) IGBT or GTO Based DC-to-AC Inverters

These inverters are used which create an output voltage wave that's controlled in magnitude and phase angle to produce either leading or lagging reactive current, depending on the compensation required.

2) LC filter

The LC filter is used which reduces harmonics and matches inverter output impedance to enable multiple parallel inverters to share current. The LC filter is chosen in accordance with the type of the system and the harmonics present at the output of the inverter.

3) Control Block

These control blocks are designed based on the various control theories and algorithms like instantaneous PQ theory, synchronous frame theory etc.. All these different algorithms are discussed in the next chapter.

III. DSTATCOM CONTROLLER

In direct-quadrature-zero (dq0) transformation or zero-quadrature-direct (0qd) transformation is a mathematical transformation that rotates the reference frame of three-phase systems in an effort to simplify the analysis of three-phase circuits. In the case of balanced three-phase circuits, application of the dqo transform reduces the three AC quantities to two DC quantities [6]. Simplified

calculations can then be carried out on these DC quantities before performing the inverse transform to recover the actual three-phase AC results. It is often used in order to simplify the analysis of three-phase synchronous machines or to simplify calculations for the control of three-phase inverters.

In this method reference currents are generated through the instantaneous active and reactive current component of the nonlinear load. In the same way three phase current component a-b-c will be transformed into α - β -0 components in stationary frames then it will be rotated by angle θ in synchronous reference frame based on the Park transformation. Further, control scheme is described how to regulate DC voltage across the DC bus capacitor and the construction of PI controller which is very important for the generation of the error signal for switching purpose. During distorted voltage condition it is found that this method is superior to instantaneous active and reactive power method.

In this method the compensation currents can be obtained from the instantaneous active and reactive current components and of the nonlinear load. By using Park transformation on two phase α - β (by Clarke transformation) we will get (d-q) components. In Park transformation two phase α - β are fed to vector rotation block where it will be rotated over an angle θ to follow the frame d-q. The calculation to obtain these components (i_{ld} , i_{lq}) follows the same method to the instantaneous active and reactive power (p-q) theory. However, the d-q load currents components are derived from a synchronous frame based on the Park transformation [7-14]. The Fig.2. Shows the space vectors representation of voltage and current.

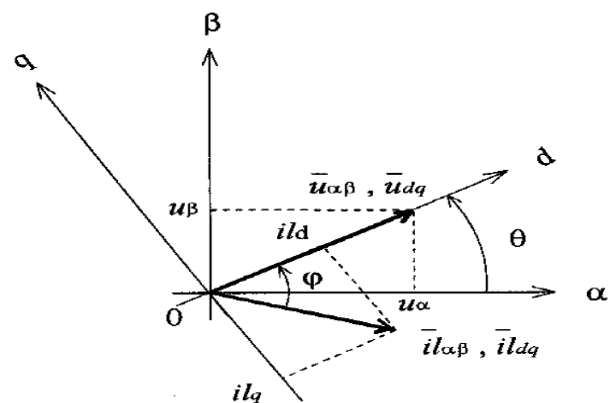


Fig. 2. Space vector representation voltage and current.

A. abc to dq transformation

abc is converted to $\alpha\beta$

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (1)$$

$\alpha\beta$ is converted to dq

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \begin{bmatrix} \cos(\phi) & \sin(\phi) \\ -\sin(\phi) & \cos(\phi) \end{bmatrix} \times \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} \quad (2)$$

Therefore abc is directly converted to dq

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\phi) & \cos(\phi-\gamma) & \cos(\phi+\gamma) \\ -\sin(\phi) & -\sin(\phi-\gamma) & -\sin(\phi+\gamma) \end{bmatrix} \times \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (3)$$

B. dq to abc transformation

dq is converted to $\alpha\beta$

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} \cos(\phi) & -\sin(\phi) \\ \sin(\phi) & \cos(\phi) \end{bmatrix} \times \begin{bmatrix} f_d \\ f_q \end{bmatrix} \quad (4)$$

$\alpha\beta$ is converted to abc

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} \quad (5)$$

dq is directly converted to abc

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} \cos(\phi) & -\sin(\phi) \\ \cos(\phi-\gamma) & -\sin(\phi-\gamma) \\ \cos(\phi+\gamma) & -\sin(\phi+\gamma) \end{bmatrix} \times \begin{bmatrix} f_d \\ f_q \end{bmatrix} \quad (6)$$

Here $\gamma = 2\pi/3$

Φ = angle between dq and $\alpha\beta$ reference frames.

C. Phase Locked Loop for DSTATCOM Controller

Grid connected operation is often utilized to increase the usability of the local power generation systems using the

photovoltaic or wind energy that cannot provide a constant power in time and region. The power factor control is known as one of the most important techniques in connecting the utility grid because the unity power factor ensures perfect transmission of generated power without the circulating energy. It is necessary for the power factor control to detect the accurate phase information of the utility voltages. Therefore, the phase-locked loop (PLL) can be considered to be an important part of grid-connected power generation systems.

The PLL technique has been used as a common way of recovering the phase and frequency information in electrical systems. In the area of power electronics, the PLL technique has been adopted for the speed control of electric motors. This is also available for generating the current references synchronized with the utility voltages in the power conversion system. A simple method of obtaining the phase information is to detect the zero crossing points of the utility voltages. However, since the zero crossing points can be detected only at every half-cycle of the utility frequency (i.e. 120 times per second), the phase tracking action is impossible between the detecting points and fast tracking performance cannot be achieved. Another method is the technique using the quadrature of the input waveform shifted by 90 degrees.

The Fig.3. shows the linearised model of three phase PLL systems. This technique is often used in the various applications for the detection of the phase or angular position. In three-phase systems, the dq transform of the three-phase variables has the same properties with this technique, and the PLL can be implemented by using the 4 transform and proper design of the loop filter. This paper describes the characteristics of the PLL using the dq transform of the three-phase variables and discusses the proper design method. In particular, the performance of the PLL is analyzed and tracking errors are derived for the distorted utility conditions, such as the phase unbalancing, harmonics, and offset. In addition to analytical studies, the experimental verifications are carried out using the digital signal processor (DSP) system under various utility conditions. The important considerations are thus provided for the design of the PLL in the three-phase grid-connected operation. Finally, the three-phase PLL technique is applied to the photovoltaic power generation system connected to the three-phase utility grid.

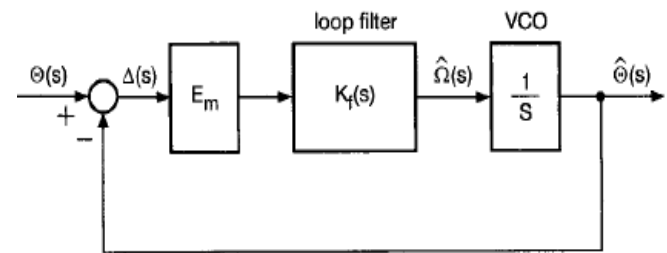


Fig. 3. Linearized model of three-phase PLL system.

D. DC Voltage Regulator

The voltage regulation on the VSC dc side will be performed by a proportional-integral (PI) controller. The input to the PI controller is the capacitor voltage error. On regulation of first harmonic active current of positive sequence $id1h+$ it is possible to control the active power flow in the VSI and thus the capacitor voltage. The reactive power flow may be controlled by the regulation of first harmonic quadrature current of positive sequence $iq1h+$. On the contrary the primary end of the active power filters is just the exclusion of the harmonics caused by non-linear loads hence the current $iq1h+$ is always set to zero. The DC voltage regulation circuit shown in the Fig.4.

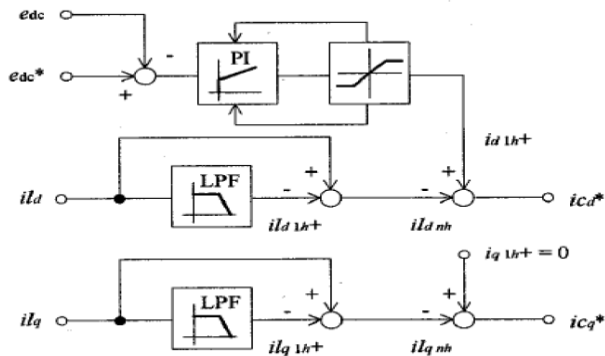


Fig. 4. DC voltage regulation circuit.

E. PI Controller

The control schemes comprises of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is studied by regulating the DC link voltage. The definite capacitor voltage will be compared with a set reference value. The error signal is then fed through a PI controller, which gives to zero steady error in tracking the reference current signal. The output of the PI controller is presumed as peak value of the supply current, which is composed of two components: (a) fundamental active power component of load current, and (b) loss component of active power filter, to preserve the average capacitor voltage to a constant value. Peak value of the current so found, will be multiplied by the unit sine vectors in phase with the individual source voltages to obtain the reference compensating currents. These expected reference currents and detected actual currents are equated at a hysteresis band, which delivers the error signal for the modulation technique. This error signal chooses the operation of the converter switches. In this current control circuit configuration the source/supply currents are made to follow the sinusoidal reference current, within a fixed hysteretic band. The width of hysteresis window regulates the source current pattern, its harmonic spectrum and the switching frequency of the devices. The DC link capacitor voltage is always preserved constant during the operation of the converter. In this scheme, each phase of the converter is measured independently. To increase the current of a particular phase, the lower switch of the converter related with that particular phase is turned on while to decrease the current the upper switch of the corresponding converter phase is

turned on. With this one can recognize, potential and viability of PI controller. The Fig.5. shows the Block representation of PI controller.

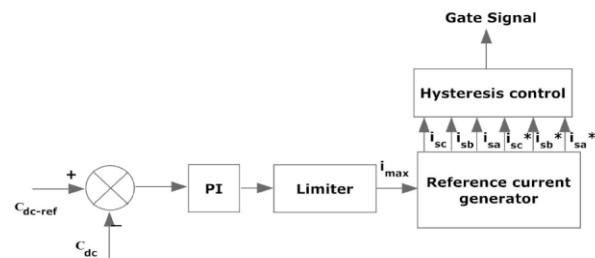


Fig.5. PI controller.

IV. SIMULATION RESULTS

The control scheme is implemented using MATLAB software. In this work, the performance of VSC based power devices acting as a voltage controller is investigated. Moreover, it is assumed that the converter is directly controlled (i.e., both the angular position and the magnitude of the output voltage are controllable by appropriate on/off signals) for this it requires measurement of the rms voltage and current at the load point.

The DSTATCOM is commonly used for voltage sags mitigation and harmonic elimination at the point of connection. The DSTATCOM employs the same blocks as the DVR, but in this application the coupling transformer is connected in shunt with the ac system, as illustrated in Fig.8. The VSC generates a three-phase ac output current which is controllable in phase and magnitude. These currents are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference.

A. Output Waveform

1) Simulation Results With-out D-STATCOM

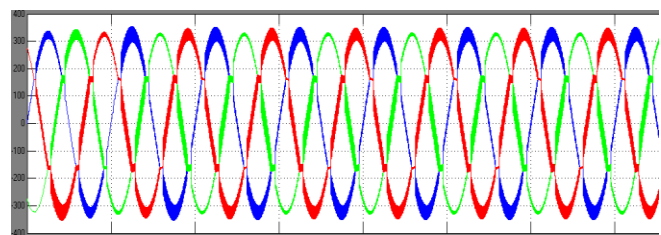


Fig.6. load voltage without D-STATCOM, x-axis in Time (sec), y-axis in amplitude (v)

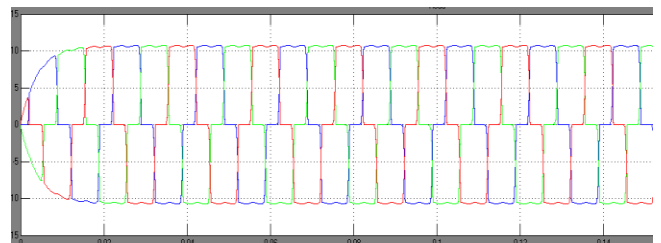


Fig.7. load current with-out D-STATCOM, x-axis in Time (sec), y-axis in amplitude (v)

2) Simulation Results With DSTATCOM

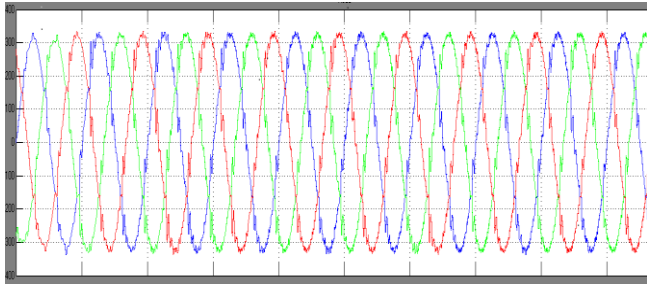


Fig.8. load voltage with D-STATCOM, x-axis in Time (sec), y-axis in amplitude (v)

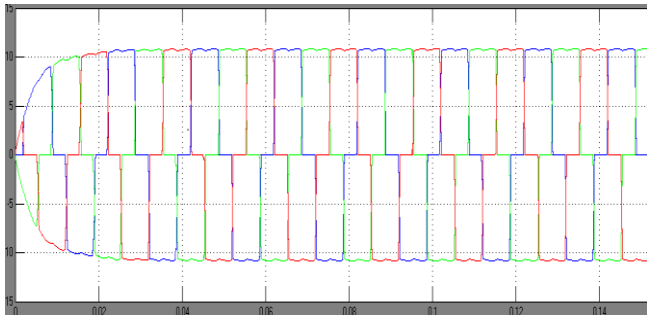


Fig.9. load current with D-STATCOM, x-axis in Time (sec), y-axis in amplitude (v)

V. CONCLUSION

The complete analysis of reactive current and voltage controllers of the STATCOM application are presented. The controllers are designed on the basis of parameters of the D-STATCOM and time constant. The simulated figures with designed controllers and on variation of DC link voltages are given which have been controlled the desired values. The settling time of the system by using the PI controller is faster than other controllers. In this project, the proposed scheme is easier to implement compared others. However, in practice the issue of the charging the DC link voltage to the required value is quite significant. On increasing the magnitude of DC link voltage, the overshoot of all signals decreases. In most cases, there is a separate charging circuit for the DC link voltage.

REFERENCES

- [1] P. Rao, M. L. Crow, Z. Yang, "STATCOM Control for Power System Voltage Control Application," *IEEE Trans. on Power Delivery*, vol. 15, no. 4, pp. 1131-1137, Oct. 2000.
- [2] W. Ren, et al. "A Multivariable Control Method in STATCOM Application for Performance Improvement," *Industry Applications Conference*, vol. 3, pp. 2246-2250, 2005.
- [3] K.R.Padiyar "Facts controllers in power transmission and distribution" new age international (P) Ltd publishers, 2007.
- [4] A. Ghosh and G. F. Ledwich, *Power Quality Enhancement Using Custom Power Devices*. Norwell, MA, USA: Kluwer, 2002.
- [5] F. Z. Peng, "Application issues of active power filters," *IEEE Ind. Appl. Mag.*, vol. 4, no. 5, pp. 21-30, Sept./Oct. 1998.
- [6] R. S. Herrera and P. Salmeron, "Instantaneous reactive power theory: A reference in the nonlinear loads compensation," *IEEE Trans. Ind. Electron.*, vol. 56, no. 6, pp. 2015-2022, Jun. 2009.

- [7] S. Rahmani, A. Hamadi, N. Mendalek, and K. Al-Haddad, "A new control technique for three-phase shunt hybrid power filter," *IEEE Trans. Ind. Electron.*, vol. 56, no. 8, pp. 2904-2915, Aug. 2009.
- [8] M. Mohseni, S. M. Islam, and M. A. S. Masoum, "Enhanced hysteresis based current regulators in vector control of DFIG wind turbines," *IEEE Trans. Power Electron.*, vol. 26, no. 1, pp. 223-234, Jan. 2011.
- [9] S. Rahmani, A. Hamadi, and K. Al-Haddad, "A Lyapunov-function-based control for a three-phase shunt hybrid active filter," *IEEE Trans. Ind. Electron.*, vol. 59, no. 3, pp. 1418-1429, Mar. 2012.
- [10] S. Srikanthan and M. K. Mishra, "DC capacitor voltage equalization in neutral clamped inverters for DSTATCOM application," *IEEE Trans. Ind. Electron.*, vol. 57, no. 8, pp. 2768-2775, Aug. 2010.
- [11] R. Inzunza and H. Akagi, "A 6.6-kv transformerless shunt hybrid active filter for installation on a power distribution system," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 893-900, Jul. 2005.
- [12] B. Singh and S. Arya, "Implementation of single-phase enhanced phase locked loop-based control algorithm for three-phase DSTATCOM," *IEEE Trans. Power Del.*, vol. 28, no. 3, pp. 1516-1524, Jul. 2013.
- [13] B. K. Bose, "An adaptive hysteresis-band current control technique of a voltage-fed PWM inverter for machine drive system," *IEEE Trans. Ind. Electron.*, vol. 37, no. 5, pp. 402-408, Oct. 1995.
- [14] S. Srikanthan and M. K. Mishra, "An improved hysteresis current control of three level inverter for DSTATCOM application," in *Proc. Nat. Power Electron. Conf.*, IISc Bangalore, India, Dec. 2007, pp. 1-6.

Silvin Daniel, PG Student, M.E-Power Electronics and drives, Department of Electrical and Electronics Engineering, M.A.M. School of Engineering, Trichy.

Ilango, Head and Professor, Department of Electrical and Electronics Engineering, M.A.M. School of Engineering, Trichy.

Prabaharan, Assistant Professor, Department of Electrical and Electronics Engineering, M.A.M. School of Engineering, Trichy.